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Strategic analysis of energy efficiency projects: Case study of a steel mill in Manitoba

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ABSTRACT

An analysis of energy efficiency opportunities at a steel mill were undertaken using two energy modeling tools, the RETScreen Clean Energy Project Analysis Software (RETScreen) and the Process Heat Assessment and Survey Tool (PHAST). A number of energy efficiency opportunities were found to be feasible in this analysis at Gerdau North America Long Steel-Manitoba Mill. The waste heat recovery opportunities included: (1) preheating combustion air in the ladle preheater, with an estimated energy savings of 22,000 GJ/yr and a payback period of 10 months; and, (2) preheating billets with an estimated energy savings of 60,323 GJ/yr and a payback period of three years. Changing natural gas space heaters to more energy efficient and safer models was both socially and economically beneficial, although having a longer payback period of 4.5 years. Oxy-fuel combustion was not deemed feasible as oxygen costs negated any natural gas savings and the productivity gains were not considered applicable. The strategic analysis showed that environmental, economic and productivity benefits were larger than the smaller concerns of: production interruption, the economic barriers of capital costs, as well as the risks posed by a downturn in the economy or by outsourcing.

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1. Introduction

Energy efficiency is the most cost-effective way to reduce energy consumption and industrial greenhouse gas (GHG) emissions in the short- to mid-term [1,2]. Energy efficiency is also considered necessary to reduce GHG by 60–80%, which is required

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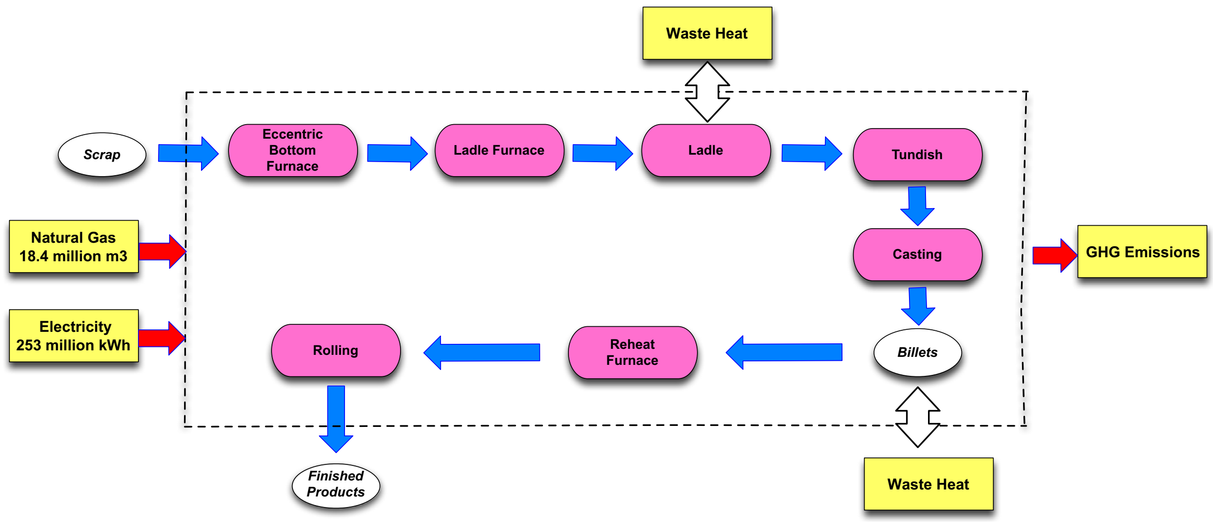

Fig. 1. Simplified production process in Gerdau Manitoba Mill.

to stabilize climate change [3–5]. This focus on energy efficiency is not only good for the environment but also profitable for industries, as it increases competeviness and productivity [6,7].

This paper analyzes the energy efficiency opportunities at the century old Gerdau Long Steel North America Manitoba plant, Gerdau Manitoba Mill (called Gerdau in this paper). As both electricity and natural gas are priced relatively low in Manitoba the incentive for energy efficiency is more reduced than in other places. As Manitoba generates 98% of its electricity from14 hydroelectric stations [8] electrical use in Gerdau does not contribute to GHGs. Gerdau is one of the biggest energy consumers in the province of Manitoba, Canada, using both natural gas and electricity [9]. In 2010, Gerdau consumed 18 million m^3 of natural gas consumption and 253, 078 MWh of electricity [9]. Fig. 1 shows the process, energy inputs and potential energy efficiency opportunities at Gerdau.

Steel has both positive and negative impacts on the environment. On the positive side, steel is continuously recyclable and therefore a highly desirable environmentally-friendly material. On the negative side, the steel industry is a significant contributor of GHG emissions and a very energy-intensive industry due to requiring very high temperatures to melt steel [5]. To lessen the negative environmental impact of steel it is important to improve energy efficiency.

In the iron and steel production sector, there are many options to improve energy efficiency and reduce GHG emissions. Energy efficiency measures include enhancing continuous production processes, waste energy recovery, changing from primary to secondary production routes and scrap preheating [6,10,11,12]. High energy costs have been the main driver of energy efficiency improvements in the steel sector in the past. However, in the 21st century, environmental regulations and carbon trading requirements are new drivers to improve energy efficiency in the steel industry.

Energy efficiency measures in the steel industry can yield large savings. Typically, energy costs are the second highest cost area in the EAF steel production [11] and so any savings can be significant. In Japan, steel manufacturers established technologies of scrap preheating in the electric arc furnace (EAF) steel production process to reduce the high electricity costs [12]. Also, Chan et al. [6] reported that hot charge rolling can achieve 30–50% total energy savings. Furthermore in Europe and the United States, high natural gas prices have steel producers using oxygen-enriched combustion to improve energy efficiency. By using flameless oxy-fuel in furnaces, the thermal efficiency is reported to reach 80% without a recuperator and the specific energy used could be less than 1 GJ/ton [13]. As a result, oxygen combustion is widely applied to electrical arc furnace for scrap melting, ladle preheating, and reheating [14,15]. By significantly reducing heating time, oxy-fuel can increase productivity by 50% [16]. An oxy-fuel burner is considered to be a highly cost effective measure in the steel sector when taking productivity benefits into consideration at a cost saving of US $1/ton [7].

An energy audit was conducted at Gerdau finding four opportunities for energy efficiency. A cost-benefit analysis was undertaken for these four opportunities aided by two different tools for energy modeling. First, the energy saving of waste heat recovery to preheat billets was examined using RETScreen International 4.0 (RETScreen). RETScreen is a clean energy project analysis software developed by Natural Resources Canada [17]. The software has been used worldwide to evaluate energy production, energy project cost and saving, GHG emissions reductions and financial viability. For instance, Bakos et al. [18] evaluated the feasibility of an integrated photovoltaic system in a grid-connected building by RETScreen. Also, Thompson and Duggirala [19] analyzed the feasibility of renewable energy at an off-grid community in Canada by RETScreen.

Another useful tool for estimating savings from recovering waste heat is the process heat assessment and survey tool (PHAST). This tool was applied to estimate the savings from recovering waste heat to preheat combustion air in the ladle preheater and oxy-fuel combustion [20]. PHAST was developed by the U.S. Department of Energy. Industries can survey heating equipment that consumes steam, electricity, or natural gas by this tool and identify the energy losses and energy efficiency potential according to different scenarios.

Other factors must be considered in determining whether an energy efficiency measure is implemented. A strategic analysis, called a SWOT analysis, is commonly used for strategic planning to evaluate internal strengths and weaknesses, as well as external opportunities and threats for projects [21]. Environment, economic and productivity benefits to energy efficiency must be weighed against threats and weaknesses.

2. Method

An energy audit was carried out for four key areas for energy optimization at Gerdau considering: (1) preheating billets using

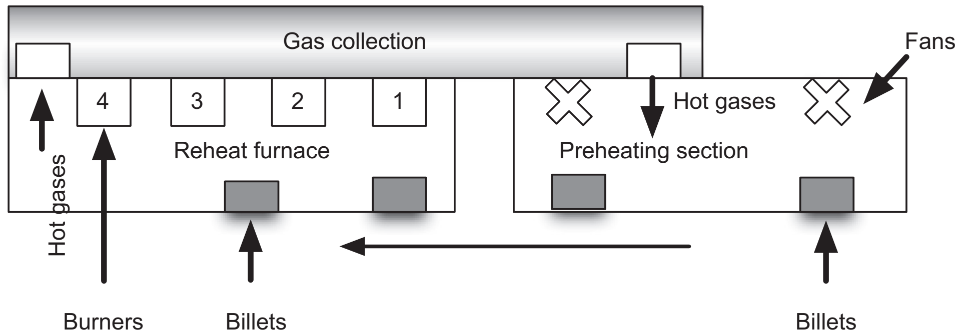

Fig. 2. The proposed preheating process for Gerdau Manitoba Mill.

waste heat (Fig. 2); (2) recovering waste heat to preheat combustion air; (3) replacing direct-fired natural gas heaters; and (4) applying oxy-fuel to the reheat furnace. During this audit data collected included oxygen (% dry) in the ladle preheater, flue gas and combustion temperature in the ladle preheater, oxygen in combustion air in the reheat furnace and flue gas and combustion air temperature in the reheat furnace.

2.1. Determined the energy savings from preheating billets with waste heat

Preheating billets with waste heat to 315 °C (600 °F) was analyzed. When the steel is cast directly into semi-finished shapes (slabs and billets) during casting processes these are stored at ambient outdoor temperature (2.7 °C) at the billet bay, and then transported to a reheat furnace where they are reheated to 1,200 °C. This study looked at preheating billets to 315 °C (600 °F) using the waste heat captured from the reheat furnace. The production data from Gerdau's production system, including heat load, duty cycle, operation hours and seasonal efficiency were obtained and the amount of recoverable heat from the reheat furnace by Eq. (1) was calculated.

$$Q = mxCpx\Delta T \tag{1}$$

where:

$M = 324{,}235{,}991$ kg (average annual production at Gerdau from 2005–2010)
$Cp = 0.12$ kcal/kg °C (specific heat in carbon steel)
$\Delta T = 312.3$ °C.

Applied the change in temperature and a $7.8/GJ fuel rate, which is the average rate at Gerdau from 2005–2010, in RETScreen's *method one, Energy Efficiency: heat recovery* [17]. See Table 1 for data inputted into RETScreen. Energy savings potential, CO_2 emission reduction and payback period were determined by RETScreen.

2.2. Calculated the energy savings from ladle preheater waste recovery

For PHAST to calculate energy consumption (GJ/h) inputs included 15 MM Btu/h as firing capacity in the ladle preheater at Gerdau [22], a flue gas temperature of 871 °C and ambient temperature of 20 °C. See Fig. 4 for other inputs to PHAST to compare the current ladle preheater to one modified to include a recuperator. Energy savings were determined using Eq. (2) (step 1) for 8016 operating h/yr at a fuel rate of $8.2/MM Btu. Eq. (3) for simple payback (step 2) was calculated considering the cost to install and purchase a recuperator of $144,017 [22]. Eq. (4) was applied to calculate the CO_2 emission reductions.

Table 1
Production data for the waste heat recovery to preheat billets.

Items	Value
Heat load (GJ/h)	94.5
Duty cycle	50%
Annual operating hours (hr/yr)	8016
Seasonal efficiency	56.4%

Table 2
Preheating combustion air in the ladle preheater.

Items	Value
Fuel saving (GJ/h)	2.75
Annual operating hours (hr/yr)	8016
Annual fuel saving (GJ/yr)	22,000
Annual energy saving ($)	$171,600
Cost ($)	$144,017
Simple payback (yr)	0.8
CO_2 reduction (ton)	1081

Step 1: Determined energy savings by Eq. (2):

$$S_E = (E_p \times H) - (E_C \times H) \tag{2}$$

where S_E is the energy savings (GJ/yr), E_P is the proposed energy consumption (GJ/h), H is the operating hours (h/yr), E_C is the current energy consumption (GJ/h).

Step 2: Calculated the simple payback period by Eq. (3).

$$Y_s = \frac{C_p}{S_a} \tag{3}$$

where Y_s is the simple payback period (yr), C_p is the project costs ($), S_a is the annual energy savings ($/yr).

Step 3: Calculated CO_2 emission reductions by Eq. (4)

$$E_R = S_E \times F_E \tag{4}$$

where E_R is the amount of CO_2 reductions per year (ton/yr), S_E is the annual energy savings (GJ/yr), F_E is the emission factor, natural gas's emission factor is 0.049 ton CO_2/GJ.

2.3. Replacing natural gas heaters with direct fired heaters

The fuel savings are estimated to be 2 GJ/h with annual energy savings of $44,928/yr. The simple payback period for $200,000 in costs was calculated to be 4.5 years. The CO_2 emission reductions are estimated to be 282 ton/yr. See Table 3 for the findings on energy efficiency.

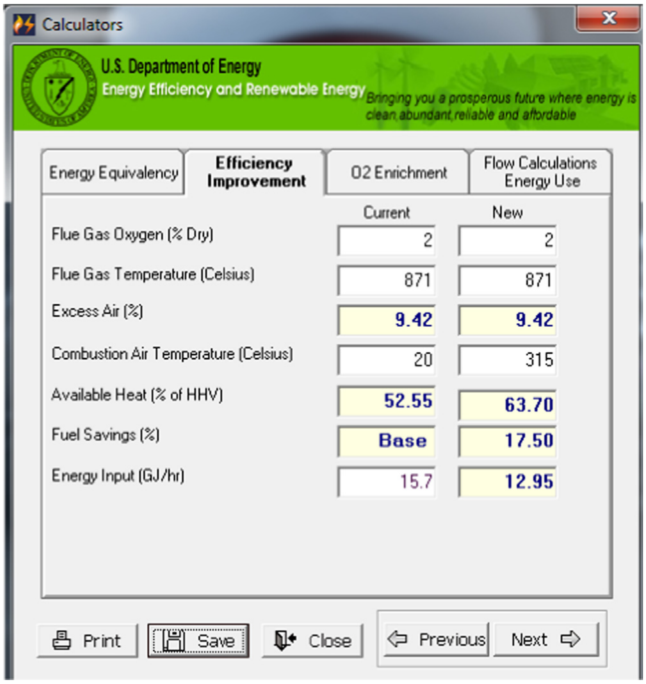

Fig. 3. Energy saving by preheating combustion air in the ladle preheater calculated by PHAST.

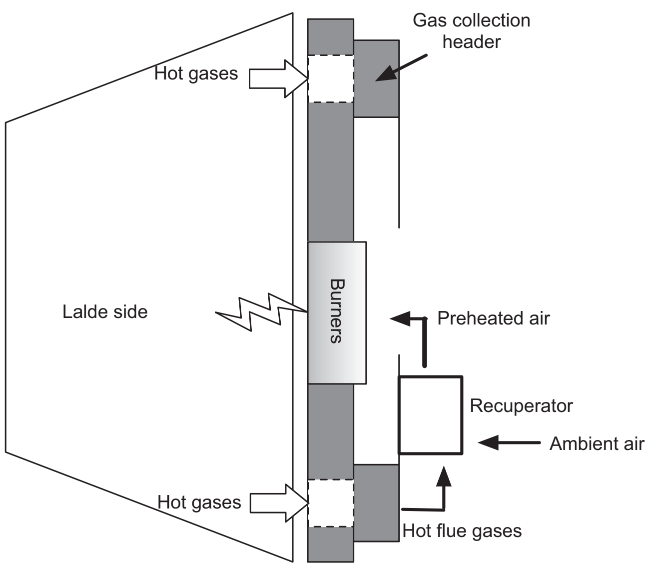

Fig. 4. The proposed scheme of preheating combustion air in the ladle preheater. *Source*: Adapted from U.S. Department of Energy [20].

2.4. Oxy-fuel combustion impacts

Analyzed the feasibility of substituting oxy-fuel for air considering 21% oxygen in combustion air, 2% oxygen in flue gases and a flue gas temperature of 800 °C. Oxy-fuel combustion was estimated by PHAST based on oxygen *stoichiometric* combustion, with one volume of natural gas needing two volumes of oxygen to completely burn. PHAST was applied using the inputs in Fig. 5. Energy savings were determined using Eq. (2) (step 1) of the fuel savings for 8016 operating h/yr against the cost to supply annual oxygen needs of 1,042,782.6 at $4.5/MCF [22]. Eq. (4) (step 3) was applied to calculate the CO_2 emission reductions. To calculate the productivity of oxy-fuel combustion in the reheat furnace Eq. (5) was applied.

Table 3
Energy saving calculation of replacing direct-fired natural gas heaters.

Item	Value
Fuel savings (GJ/h)	2
Annual operating hours (hr/yr)	2880
Annual energy saving ($/yr)	$44,928
Costs ($)	$200,000
Simple payback period (yr)	4.5
CO_2 reductions (ton/yr)	282

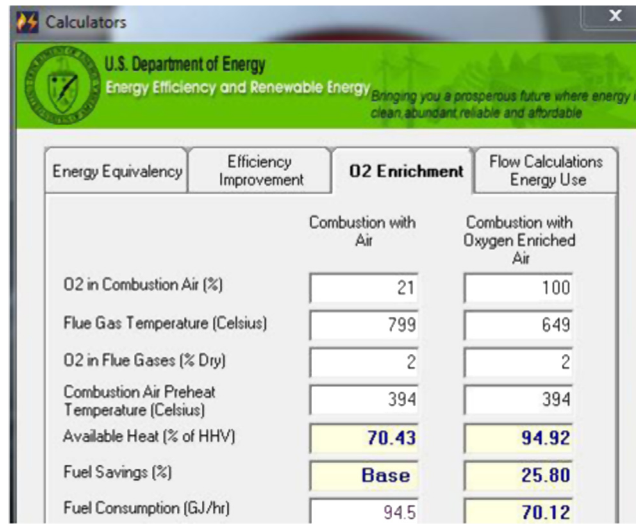

Fig. 5. Energy saving by oxyfuel combustion according to PHAST in the reheat furnace.

$$B_p = P_i \times P_b \times P_p \tag{5}$$

where B_p is the productivity benefits by production improvement ($/yr), P_i is the production improvement (ton/yr), P_b is the billet's price ($/ton), P_p is the net profit margin (%).

3. Results

3.1. Recovering waste heat to preheat billets

Preheating billets to 315 °C decreases energy consumption by 60,323 GJ/yr, according to the RETScreen analysis. The annual natural gas saving is estimated to be $470,519/yr when the rate is $7.8/GJ. The estimate of GHG reduction is 2999 ton CO_2/yr. The simple payback for the project is estimated to be 3 years based on an initial cost of $1.25 million, 5% inflation rate and an annual maintenance cost of $50,000. The project life span chosen was twenty years. See Fig. 3 for the proposed preheating process noticing that the preheating section uses the flue gas from the reheat furnace, piping it into an enclosure situated proximate to the opening of the reheat furnace.

3.2. Recovering waste heat to preheat combustion air in the ladle preheater

Fig. 4 shows that preheating for the ladle is estimated by PHAST to save 2.75 GJ/h or $171,600/yr (Fig. 5, Table 2). The payback

period is estimated to be 10.1 months for the project cost of $144,017 [22]. The CO_2 reductions are 1,081 ton/yr.

3.3. Replacing natural gas heaters with direct fired heaters

The fuel savings are estimated to be 2 GJ/h with annual energy savings of $44,928/yr. The simple payback period for $200,000 in costs was calculated to be 4.5 years. The CO_2 emission reductions are estimated to be 282 ton/yr. See Table 3 for the findings on energy efficiency.

3.4. Estimating fuel use potential by oxy-fuel combustion

Oxy-fuel combustion was estimated by PHAST based on oxygen *stoichiometric* combustion, with one volume of natural gas needing two volumes of oxygen to completely burn to offer 25.8% energy saving. The energy saving is 195,430 GJ/yr or $1.5 million/yr (Table 4). At $158.9/10^3 m^3 for 30 million m^3/yr of oxygen will cost $4.8 million (Table 4). Under current natural gas rates and oxygen rates, the oxygen cost for this operation surpasses gas savings. As oxy-fuel significantly reduces heating time, which increases productivity, 50% increased productivity is estimated [14], which could impact annual production by an estimated 324,236 ton/yr at Gerdau, to create a net profit margin increase of 8% [13]. An increased productivity of 50% would yield $7.1 million/yr from oxy-fuel combustion if applicable (Table 5). However, the management at Gerdau felt that these productivity increases were not applicable due to other restrictions and so were not considered in determining payback periods.

Table 4
Energy saving estimates for oxyfuel combustion at Gerdau Manitoba Mill.

Item	Value
Fuel savings (%)	25.8%
Annual operating hours (hr/yr)	8016
Fuel savings (GJ/yr)	195,430
Annual gas saving ($/yr)	$1,524,354
Annual gas with oxyfuel (10^3 m^3/yr)	15,029
Annual oxygen needs (10^3 m^3/yr)	30,058
Oxygen rate ($/$10^3$ m^3)	$ 158.9
Annual oxygen cost ($/yr)	$ 4,776,216
Saving/(cost)	$ (3,251,862)
CO_2 reduction (ton/yr)	9576

Table 5
Estimated benefits to productivity from oxyfuel combustion at Gerdau Manitoba Mill.

Item	Value
Annual production (ton)	324,236
Annual production improvement (ton)	162,118
Billets price ($/ton)	550
Net profit margin (%)	8%
Productivity benefits ($/yr)	$7,133,192

3.5. Strategic analysis for SWOT

A strategic analysis evaluated the energy efficiency opportunities based on strengths, weaknesses, opportunities and threats, also known as a SWOT. See Table 6 for the environment and economic benefits of energy efficiency projects at Gerdau, which are very positive on energy savings and CO_2 reductions. These results can be considered in the context of an expanding steel industry and a trend towards increasing regulation of GHGs. Steel use is increasing globally. World steel is expected to reach 55 billion tons in 2050, which is four times more than the world steel use in 2005 [23]. Construction and demand for vehicles are the main drivers for the increasing demand of steel over the long term [23]. However, steel production is shifting from developed countries to developing countries to reduce labor costs and to lessen stringency of environmental regulations.

The case for energy efficiency is weakened by the need to interrupt production to install the new equipment. For example, installing oxy-fuel operation requires changing burners and upgrading control systems handling systems. Gerdau operations run 8016 h/yr but annual maintenance measures require a shut down in the summer, which could allow energy efficiency measures to be undertaken without further interruptions to production. Another barrier is the capital investment required for energy efficiency projects [24,25,26]. Although government and local utilities provide many incentive programs for energy efficiency projects [27,28], these normally do not provide all the funding needed to carry out a project and are not always applicable.

Opportunities that make a case for energy efficiency include the increasing stringency of regulations for GHG reduction. Energy efficiency measures that reduce GHG emissions should provide cap and trade benefits in the future. Manitoba as a member of the Western Climate Initiative (WCI) has committed to reduce emissions by 15% below 2005 levels by 2020 through a cap and trade program [29] including iron and steel manufacturing emissions [30].

There are threats that should be considered in deciding whether to proceed with an energy efficiency project. Adverse outcomes could result from economic recession. Short-term recessions can impact steel use and make energy efficiency projects unviable. For example, Gerdau reduced its production in 2008 and 2009 as market demand was decreased. Industries tend to rein in spending as a defensive approach to deal with the recession: International Energy Agency (IEA) reported that energy investment in most regions and sectors dropped significantly due to the global economic crisis [31], which results in delaying implementation of energy efficiency projects. A drop in energy prices could prevent a good return on investment. With natural gas prices at a

Table 6
Environment and economic benefits of energy efficiency projects at Gerdau Manitoba Mill.

Project name	CO_2 reduction (ton/yr)	Fuel saving (GJ/yr)	Annual saving/cost ($/yr)	Initial cost ($)	Payback period (yr)	Feasibility (Y/N)
Preheating billets to 315 °C[a]	2999	60,323	$ 470,519	$ 1,250,000	3.0	Y
Recovering waste heat in the ladle preheater	1081	22,000	$ 171,600	$ 144,017	0.8	Y
Replacing direct-fired natural gas heaters[b]	282	5760	$ 44,928	$ 200,000	4.5	Y
Oxyfuel	9576	159,430	$ (3,251,862)	–	–	N

[a] Initial cost is estimated based on preheating section is 1691.64 cm long.
[b] Replacing direct-fired natural gas is to comply with Canada's natural gas installation code, the energy saving depends on operating capacity.

low point, having dropped 50% since 2008 [31] the economic rationale for energy efficiency is reduced. The energy price of natural gas now is much lower than $7.8/GJ, which is Gerdau's average price over six years, from 2005 to 2010.

The other threat is outsourcing to a developing country and moving the steel mill. In developing countries labor costs are lower and environmental regulations are less stringent. If a company has a plan to outsource their manufacturing to developing countries as a mid-term strategy, energy efficiency projects that generally have a three to five year payback are not considered desirable.

4. Conclusion

This study showed that energy efficiency projects can have good financial returns and short payback periods. Thus energy efficiency projects make good business sense now and even better business sense in the future with trends for escalating fossil fuel prices. After an energy audit and strategic analysis of energy efficiency at Gerdau, the following projects are considered feasible: (1) recovering waste heat to preheat billets, with an estimated 60,323 GJ/yr energy savings and a 3 year payback period, (2) using waste heat to preheat combustion air in the ladle preheat with an estimated 22,000 GJ/yr energy savings and a 10 month payback period, and 3) replacing direct-fired natural gas heaters with an estimated 5760 GJ/yr energy savings. Oxy-fuel combustion is not deemed feasible as the high oxygen costs negate any natural gas savings and the productivity gains were not considered applicable in this case.

This case study demonstrates that energy efficiency projects have many benefits. These positive impacts include: (1) reducing emissions and environmental impacts, (2) decreasing fuel use, (3) providing savings annually after a short payback period, and (4) increasing productivity. Although production downtime, during the installation of energy efficiency equipment, and capital costs pose economic barriers to implementing energy efficiency projects, government and utility incentive programs are available to help reduce the financial burden. Since environmental regulation and steel production are increasing the only big threat is outsourcing to developing countries, which in the case of Gerdau is unlikely due to its unique product lines.

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